Base Module 2
Operating Principle Barrier - Introduction 2

This module covers the technical layout of the Maeslant Barrier, also called Storm Surge Barrier in the New Waterway (SSBNW).
The Maeslant Barrier consists of nine main components. This handbook covers the purpose of each main component, as well as the development of its construction at the time. Thus, the module gives a very thorough overview of the applied technologies.

Figure 1 on page 2 gives an overview of the Maeslant Barrier. You can take this page from the module and always have the overview of the Maeslant Barrier at hand.

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Figure 1
Overview Maeslant Barrier

1. Abutment
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1 Abutments

The land parts that protrude into the river – the abutments on both sides of the river – provide the space for the two halves of the Barrier. Therefore, space is also available for the parking docks and the lattice arms with the joint foundations.

The navigable section, with a width of 360 meter, has remained fully unchanged. A so-called combi wall was chosen for the front wall of the abutments.

**Figure 2**
The combi wall principle

A combi wall is a steel sheet piling, created by placing a double sheet piling board between two tubular piles. Sheet pile locks/slots, into which regular sheet piling profiles fit, are welded to the piles. The original shore defense had to be removed first before the combi wall could be driven into the ground.

**Figure 3**
Pile-driving pontoon
Source: BMK

The diameter of the piles ranges from 910 to 1,620 mm; the longest pile is 30 meters long. The piles were driven into the ground with great accuracy. This required accuracy was realized by using a guide framework during positioning. As soon as the wall was ready, soil was added behind it, up to 3.5 meter below Amsterdam Ordnance Datum (NAP). The abutment was created by means of sand nourishment. Excess water could disappear through temporary openings in
the wall. Prior to the application of a new layer of sand nourishment, deposited river silt was removed with the aid of an air-water jet.

The combi wall was anchored in order to counter the response from the soil pressure.
Each tubular pile in the wall was equipped with anchoring wire or anchor rods connected to a support wall, the anchor wall, which is located at approximately 30 meters from the tubular piles.

![Anchoring wires and combi/anchor wall dock](image)

The anchor wall consists of sheet piling with a concrete anchor beam behind it. Retention anchors are located in this anchor beam. This way, the combi wall absorbs the soil stresses and hence becomes soil-retaining.

The walls of the parking docks were also carried out as combi walls. A pile-driving pontoon was required for the part that is located in the water. Whenever there was insufficient room for the usual tension wire anchoring, the same effect was achieved by using steel raking piles.

**documentation**

More information is available in documentation M00-ALG-07-EN Handbook 5.
2 Parking dock

The role of the parking dock is to provide parking for the Barrier in a controlled environment. When parked, the retaining wall rests on fourteen support seats (or pedestals) of which thirteen are in the dock and one just outside. The dock’s depth ranges from 8.0 m below Amsterdam Ordnance Datum (NAP) on the landward side to 8.9 m below Amsterdam Ordnance Datum (NAP) on the riverward side. This is ample for allowing the retaining wall to float. When floating, the retaining wall’s draught is about six meter. The dock is equipped with three pumps, which can empty the dock for inspection and maintenance to the retaining wall as well as to the dock.

In principle, the water level in the dock in parking position is always lower than the lowest water level in the river (the standard control water level of the dock is 1.90 m below Ordnance Datum). The water level in the river may become lower, but only in rare circumstances. In that event, the gates of the dock door will open automatically to relieve the supporting blocks of the dock door. In the normal situation, the pressure difference between exterior (river) and interior (dock) levels is sufficiently large to press the seal of the dock door shut. Leakage is minimal in that situation. At the standard control water level, the retaining wall is securely supported on the pedestals.

![Figure 5](https://example.com/figure5.jpg)

Figure 5
Combi wall and anchor wall parking dock; the wall on the right is the dock wall, the wall on the left the anchor wall
Source: BMK

The dock floor is subjected to greatly varying loads. When the dock is filled, the piles under the dock floor under pressure, and when the dock is empty, the floor is under tension as a result of the water pressure under the floor, and under pressure as a result of the retaining wall’s weight on the pedestals. The dock floor consists of a layer of underwater concrete with a strongly reinforced construction-concrete floor on top.
construction of the dock

The dock’s construction consisted of the following phases:

- driving of the dock walls (combi walls), partly from the water, partly from (new) land;
- placing of the anchor walls and anchoring between dock wall and anchor wall;
- excavation between the dock walls (to approximately 11 m below Amsterdam Ordnance Datum (NAP)) and cleaning of the walls;
- driving of the (562) VIBRO combination piles;
- application of layer of underwater concrete (thickness 1.1 m);
- emptying of the dock and construction of the constructive floor with the pedestals;
- construction of a concrete cap at the top of the sheet piling.

VIBRO combination piles

A VIBRO combination pile is a pile that is shaped inside the ground and is excellently suited for absorbing both pressure and tension loading. A tube (casing) with a separate lid at the bottom is driven into the ground to the desired depth. Next, a prefab concrete pole is lowered into the tube. During removal of the casing, concrete is added to obtain good adhesion with the surroundings. The lid at the bottom (the baseplate) remains behind.

The application of underwater concrete was chosen, among other things, because deep drainage by well points would lead to withdrawal of groundwater even in distant surroundings. The underwater concrete needed to be applied precisely. Good adhesion with the dock walls and the piles was important so as to achieve sufficient strength and to limit leakage. The precision of its top was closely related to the constructive floor to be mounted on top. The role of the underwater concrete was a temporary one. The constructive floor, as explained before, serves to absorb all loads during actual use.

A distributing and working layer of approximately 15 cm of sand was applied between the constructive floor and the underwater concrete. The thickness of the constructive floor ranges from 0.6 to 0.9 meter.
covering sole-piece, the cap

Finally, the combi wall of the parking dock was capped with a covering concrete sole-piece, the cap. This is a continuous concrete perimeter beam on top of the combi wall. When parked, the retaining wall rests on fourteen supporting points; these are concrete columns called pedestals. The dock contains thirteen of them, and one more is located just outside the dock.
dock door

The dock door closes off the entrance to the dock to the river and rolls on a rail. At the entrance, the width of the dock is 17 meters, which is less than the normal dock width of 20.5 meters.

The main functions of the dock door in closed position are the following:
- separating the parking dock from the river;
- protecting the retaining wall against ship collisions;
- enabling emptying of the dock in order to carry out inspections and maintenance to the retaining wall.

The ample width of the dock allows the placement of scaffolding to work on the retaining wall. This width also provides tolerance so that sufficient space remains between retaining wall and dock entrance when the joint rotates.

documentation

More information can be found in documentation M00-ALG-03-EN Handbook 1.
3 Ball joint, joint foundation

3.1 Ball joint
The ball joint is one of the most crucial components of the Maeslant Barrier. Everything literally revolves around it.

**function of the joint**
The function of the joint is two-fold. Firstly, the joint is the pivot point of the sector door. Secondly, the water pressure exerted onto the retaining wall is transferred to the joint foundation, via the lattice arms and the joint.

**ball joint**
A ball joint was chosen as the retaining wall’s hinging solution, as only a ball is capable of enabling all movements of the sector door. When the Barrier is closed, with the water level behind the Barrier being 4 meter lower, the total water pressure is 25,000 ton, or 250 MN, on one Barrier half or retaining wall. This water pressure from sea provides a positive differential head.

**rear seat**
The positive differential head is transferred to the rear seat (the fixed part of the bearing), which measures 5 by 7 meter. The design force for the positive differential head is 35,000 ton (350 MN). When the difference in water level exerts a pressure from the river, there is a tensile force on the joint. That is a negative differential head.

This negative differential head is absorbed by the much smaller front seat.

**front seat**
The front seat is much smaller as the construction does not make it possible to have a larger front seat. The tensile force can be about 6,500 ton, or 65 MN, which translates into a water level difference of approximately 1.50 meter.

![Figure 8](image-url)
*Figure 8 Components ball joint*

The ring-shaped lower linings of the joint transfer part of the weight of the entire construction via eight lower seats. The deadweight of the ball joint and part of the lattice arms is approx. 3,300 ton or 33MN.
As the rotation angles are limited – 53 degrees horizontally and 2.8 degrees vertically – it was not necessary to produce an entire ball. It was sufficient to have segments of a ball.

In the starting situation, the shells and seats at the front and at the rear are next to each other, hence freely accessible for maintenance and repairs. They will only become closely abutting upon rotation. When the sector door departs from the dock, the ball joint slides only across the lower shells. There is space between the shells and the seats at the front and the rear at that point. During and after sinking, at an increasing water pressure from sea, the ball is pressed into the rear seat.

**Figure 9**
*Rear seat and lower seats*
*Source: BMK*
In wait position, the ball is at a distance of a few centimeters from the lower shells. This is accomplished by six jacks under the ball joint, each with a capacity of 1,000 ton or 10 MN. The ball joint can be jacked up approximately 50 centimeter for overhauls of the lower seats and lower shells.

Special attention was paid toward developing a suitable gliding system for the seats and shells. A problem is that although many coatings do have a very low frictional resistance during movement, they also need to have that at the start of the movement but don’t. Eventually, a system was devised that offered low resistance, but could also withstand high pressures.

**pads**

In practice, however, the gliding system did not perform well enough. Regularly, there was damage to parts of a ball joint after a performance closure. Repairing these damages was complicated and costly. In addition, the gliding system was sensitive to moisture and dirt, and contained toxic components. After an extensive investigation, a solution was chosen for which approximately 460 synthetics pads were mounted on the seats of each joint. In 2003, the joint on the South side was fitted out accordingly and in 2004, the joint on the North side. Also, regular means of preservation were applied to the convex parts of the joints. After these adaptations, the ball joints exhibited no further problems.

The diameter of one ball is 10 meter. Skoda in the Czech Republic supplied the cast-steel shells and seats. Their finishes were also realized at Skoda.

**core**

The core, which was built from steel sheets, was made in the Netherlands. After assembly, a floating crane was used to place the complete ball joint onto the lower shells.

![Figure 10 Placing of ball joint](image). Source: BMK
A protective steel housing was placed around the entire ball joint. In this housing, air pressure and humidity are controlled. The entire area is sealed with rubber strips and over-pressure in the interior of the joint housing keeps dust outside.

3.2 Joint foundation

When the Barrier is closed and at a positive differential head of 4 meter, the enormous water pressure of 25,000 ton or 250 MN will eventually end up on the concrete foundation, via the rear seat of the bearing. The joint foundation is a container that has the shape of a triangle with sides of about 70 meter, and a total weight – concrete and ballast gravel – of 52,000 ton (520 MN).

![Figure 11](Joint foundation under construction)

Source: BMK

friction

This foundation was designed for friction. This was realized by compacting the underground. Walls were inserted under the continuous baseplate of the foundation, perpendicular to the direction of loading. These walls extend 2 meter deeper into the compacted sand, are called skirts and are comparable to ridges on the soles of shoes.

backward displacement

Soil mechanics consultancy revealed that a small backward displacement during Barrier operations had to be taken into account. As a result of the mechanical properties of the earth body under the joint, some rebound does occur, but there is always some permanent displacement. This “walking” of the entire joint and its foundation does not impact the Barrier’s functioning, as it was taken into account in the design. Constructing the concrete joint block was a tour de force in terms of concrete technology.

A second sheet piling was applied in order to limit any damage to the combi wall in the vicinity of the concrete foundation as a result of colliding ships. About 10 meter behind the combi wall of the abutment, this anti-scouring sheet piling was inserted. In the event of a shipping incident, it keeps the compacted sand body under the foundation intact.
More information can be found in documentation M00-ALG-06-EN Handbook 4.

Figure 12
Joint foundation
Source: BMK
4 Sill and riverbed protection

The functions of the sill and riverbed protection are the following:

- providing a fixed stop for the sunken Barrier;
- limiting leakage under the Barrier as much as possible;
- fixating the sandy riverbed, at the location of the Maeslant Barrier.

When the sector doors have sunken in the New Waterway, they rest on concrete sill blocks with large bumpers called fenders. The sill blocks also serve to stop water flow under the Barrier, and to protect against erosion. Under the sill blocks are four layers of stony material with a filter-like construction. On top of the silt-containing sand, with a grain size of 0.2 mm, is a layer of coarse sand with a diameter of 0.5 to 5 mm. Next is a layer of gravel with a grain size of 3.5 to 35 mm. The third and fourth layers are supporting layers of rubble.
During the construction of the sill, the original riverbed was first deepened to a depth of 15 meter to approximately 22 meter below Amsterdam Ordnance Datum (NAP). The four filter layers each have a thickness of 0.5 to 0.75 meter. This way, the fine sand grains of the riverbed cannot be washed out. It is impossible for the fine riverbed sand grains to permeate through the pores of the coarser sand on top of it. This applies at all possible water flows. The filter is water-permeable, but impermeable to sand. This is called a geometrically closed filter.

Particularly the application of the four-layer filter in the river became a unique operation. After all, the water continued to flow, with two high tides and two low tides, and hundreds of ships passing every day.
The first two layers of the filter, sand and gravel, were poured with a pouring pipe and distribution aperture, reaching to just above the riverbed. The third and fourth layer of the filter, fine and coarse rubble, were poured from the surface with a rock dumper.

The upper rubble layer forms the foundation for the sill blocks. For this purpose, the top had to be smoothened first. The obtained precision was + or − 10 centimeter. Next, the sill blocks were placed. The sill blocks, with dimensions of 15 by 5.6 meter and a height of 3.2 meter, each have a weight of 630 ton (6.3 MN). They were built in Kats in the province of Zeeland, and transported with pontoons. A floating crane was used to put each of the sill blocks in place. To this end, a hoisting frame with a measuring tower was mounted on the sill block first. During sinking at low river flow, the measuring tower, which was equipped with measuring points, always protruded above the water. The use of geodesic equipment, linked to distance measurements, ensured proper positioning.

The result is that the elevation of the 64 sill blocks is within the accepted margin; they are all within + or − 7 cm.

Afterward, the blocks were embedded further, with rubble closely abutting the fourth filter layer. On the seaward side of the sill, boulders of 300 to 1,000 kg each were used, and on the riverward side, boulders of 3 to 6 ton each.

On the river banks, on both slopes, which have a length of nearly 25 meter, and slope down from 11 to 17 meter below Amsterdam Ordnance Datum (NAP), a different sill construction was used. Instead of concrete blocks, blocks of natural stone with a weight of 10 to 15 ton each were used. This suffices as the Barrier does not need to be supported here.
In terms of technical implementation, constructing the sill was a marvel of hydraulic engineering. Particularly the in-situ application of a four-layer filter bed and smoothing it was an impressive display of high-tech, innovative hydraulic engineering.

documentation

More information can be found in documentation M00-ALG-07-EN Handbook 5.
5 Lattice arms

The lattice arms form the connection between the Barrier halves and the ball joints. Their role is to transfer the water pressure on the Barrier to the ball joints. The force exerted by a water-filled retaining wall onto the sill amounts to maximally 10,000 ton (100 MN). The water pressure on the retaining wall is 25,000 ton (250 MN) at a water level difference of 4 meter. This latter force clearly overpowers the friction between Barrier and sill. The lattice arms transfer this enormous water pressure to the ball joints, and from there, to the concrete foundations of the joints.

Calculations, model test and wind tunnel experiments resulted in triangular constructions. This has advantages over tubular constructions. The pipes of the main construction have a diameter of 1.80 meter and the triangular shape – of the cross-section – of the arms has a base of 15 meter and a height of 18 meter. The thickness of the pipe walls ranges from 55 to 90 mm. The eventual shape of the lattice arms was determined with the aid of modern computation methods. Per sector door, there are two lattice arms, which also have a connection, the coupling joist.

Where they meet the Barrier and the ball joint, the main pipes and the lower struts have transition pieces of cast steel. These transitions go from a round to a rectangular cross-section. In total, 14 transition pieces were used. The length of the lattice arms is 238 meter.

If you look at the lattice as a spatial construction, then the lattice girder bars or diagonally running pipes are the connecting elements between the three main pipes. The diameter of these pipes ranges from 0.5 to 0.8 meter. Their wall thickness is 12 to 25 mm.
The lower four main pipes, with a diameter of 1.80 meter, have a second role during sinking of the Barrier. If they were closed, they would have significant buoyancy. Therefore, these pipes too become filled with water upon sinking. To that end, each pipe has six oval-shaped inflow and outflow openings for (ballast) water. Upon sinking, approximately 2,000 cubic meter of water flows into the four pipes.

The top pipe with a diameter of 1.80 meter is closed and always remains above water. The cables for the power supply and control run through these pipes to the Barrier. Via flexible cable transitions at the ball joint, the required 53-degree rotation can be realized.

**Manufacture of the lattice arms**
Owing to improved material properties, good welding techniques and a protective work environment, and some extra effort, it was possible to assemble the lattice arms at the Barrier location. The pipe sections of the lattice were made at the SIF plant in Roermond. In lengths of 60 meter, they were transported to the preservation hall in Krimpen aan de IJssel, via the rivers. After application of a two-layer paint system, transport to the Barrier location followed. Wheel transporters were used to place the pipe sections on temporary supports.

**welding tents and cabins**
Assembly took place next, with the aid of welding tents and cabins. The connections were welded in these shielded areas, in optimal conditions.

**documentation**
More information can be found in documentation M00-ALG-04-NL Handbook 2.
6 Retaining wall

When sunken, the Barrier halves form the water-halting elements. Each Barrier half or retaining wall consists of 28 separate sections: 13 buoyancy chambers and 15 upper casings. The upper casings and the buoyancy chambers were built separately, at two steel construction companies. Proper dimensioning of those parts was important as they needed to be fit together on location. The sections were transported to the location every four to six weeks. Each time, a complete set (buoyancy chamber and upper casing) was delivered. Transport and subsequent assembly were accomplished with the aid of floating cranes and wheel transporters.

The shape of the lower part of the Barrier, the buoyancy chamber, became very complex in terms of design technology. Extensive model testing was carried out in the hydraulic research lab. This revealed that the sector door, in certain conditions, would start to swing uncontrollably.
buoyancy chamber

The original shape caused the development of a transverse wave between the abutments on the downstream side. The energy in these transverse waves increased significantly by the interaction between water and Barrier, as a result of which unallowable movements and forces developed. The phenomenon occurred at a positive as well as a negative differential head. The manifestation of the instability, however, did differ. To eliminate the phenomenon, the shape of the buoyancy chamber had to be adjusted such that the Barrier would float as much as possible on the upstream water level.

skirts

To achieve that, the front plane was beveled off and equipped with a skirt with a height of one meter. A skirt was also needed at the rear side. The rear skirt combats a different form or instability, namely the radial vibration (a so-called self-excitation).

fenders

Fenders were added under the Barrier; with the aid of large rubber cylinders, they ensure a soft landing on the sill. The fenders function as bumpers between the steel underside of the sector door and the concrete of the sill blocks. The sill blocks were placed in the river with an elevation tolerance of ±10 cm. The heights of the large rubber cylinders in the fenders were adjusted for the height differences in the position of the sill blocks (so-called contra-molding).

compartments

Each Barrier half is divided into 13 compartments that are equipped with valves. The number of compartments is related to failure probability: If there are more compartments, the chance that the Barrier is unable to float in the event of leakage of a compartment.

The farthest two compartments on each side of the Barrier have a stabilizing role and are therefore called trim tanks. Of the other compartments, the tanks in the upward-sloping part of the compartment – the upper casing – also have water level regulation. To this end, each of these compartments has a perforated bottom. The trim tanks help enable good control of sinking and floating of the Barrier.

The central part of each Barrier half consists of compartments in which the upper casings are carried out as tanks. These upper casings are separate from the buoyancy chamber. On the seaward side, this central part is equipped with slot-shaped inflow openings. These inflow openings are visible in Figure 17 as the small dark openings just above the water level.
During sinking of the sector door, which takes place by opening the valves in the compartments of the buoyancy chamber, the inflow openings end up under water automatically. As a result, the compartments of the upper casings in the central part become filled with water, following the exterior water level.

**ventilation lines**

Upon filling of the tanks with water, the trapped air can escape via ventilation lines. When the sector door has to start floating again (lift), pumping installations are activated in all compartments of the buoyancy chamber. Lifting allows the water to flow out via the openings of the upper casings. The venting lines then become aeration lines.

The pumps needed for ballasting and deballasting obtain their power from cables that enter the electricity rooms of the Barrier via the upper pipe of the lattice. As this route is long, the electricity is supplied as 10 kV, and reduced to 400 V in two transformer rooms in the upper casings, and distributed from there.

The Barrier’s total height is 22 meter. When resting on the sill, which is 17 meter below Amsterdam Ordnance Datum (NAP), the top of the Barrier is therefore 5 meter above Amsterdam Ordnance Datum (NAP), on average.
Assembly connections were used to couple the buoyancy chamber and the upper casing to each another, after which they were rolled across the dock floor. Next, welding accomplished the final connections to the rest of the Barrier. Here too, the quality of the welded joints was safeguarded by working in welding cabins.

A special assembly method was required for coupling the complete lattice arms to the fully welded Barrier.
Each of these large steel constructions deform under the influence of daily temperature fluctuations. The length of the lattice arms, 238 meter, displays a difference of a few centimeters between day and night. Coupling took place while the retaining wall was transitioned into a floating condition.

![Coupling lattice arm to retaining wall](source: BMK)

After proper positioning of lattice arm and retaining wall, the main pipes of the lattice and the struts were welded to the retaining wall. The water level in the dock was regulated. The desired position could be maintained by regulating the water level in the buoyancy chambers of the retaining wall. The temperature of the retaining wall was kept constant by a film of water pumped from the dock.

After allowing the welded, and now complete, steel construction to float, the temporary supports under the main joists of the lattice arms could be removed.
Figure 21
Front view retaining wall
The front view of the retaining wall possesses the following characteristics:

- Most of the retaining wall will rest on the sill. Depth when sunken: 17 meter below Amsterdam Ordnance Datum (NAP).
- A small part of the underside is sloped to match the slope of the land. The depth runs from 17 meter below Amsterdam Ordnance Datum (NAP) to 12 meter below Amsterdam Ordnance Datum (NAP).
- In departed situation, a small part of the retaining wall remains behind in the dock, having just cleared the dock door-opening and still remaining in the mouth of the dock for a length of a little over ten meter. The reason for this is to limit water circulation.
- A part of the sector door does not extend into the water and therefore is not water-halting; this part forms the “parking space” for the locomobile.
- The underside of the retaining wall (in high position) displays a slight camber, or bulging, of approximately 1 meter.

The latter ensures that the retaining wall fits well on the sill. If the underside of the retaining wall were completely straight, there would be a great deal of leakage at the ends, as a result of the vertical rotation caused by sinking; the retaining wall would not be resting on the sill there.

**camber**

That is why a bulge (camber) was incorporated; at the center, the underside of the retaining wall is 1 meter higher than at the ends. This arc shape can also be found in the camber of the top of the buoyancy chamber. The upper side of the retaining wall is entirely straight, because of the toothed rack on it.

In the parking dock, the sector door rests on 13 supporting points and on one supporting point just outside the dock. The supporting blocks were constructed in such a way that expansion and shrinkage of the sector door caused by temperature differences and so on are absorbed.

**documentation**

More information can be found in documentation M00-ALG-04-EN Handbook 2.
7 Drive mechanism with guide installation

7.1 Retaining wall

The main movements of the retaining wall can be divided as follows:
- the horizontal movement: the departure and return;
- the vertical movement: sinking and lifting.

Figure 22
Drive of the retaining wall
The vertical movement is arranged by a ballast system. While departing for a closure, the Barrier will start to heave like a ship. The powering mechanism, the locomobile, which stands on top of the Barrier, moves along with the Barrier. That up-and-down movement up to over 1 meter in a few seconds has to be possible.

Furthermore, a vertical movement is needed for sinking and lifting. This vertical movement is made possible by a vertical bogie, which is connected to the locomobile, and runs along guide rails in the guide tower.

**Figure 23**
The guide tower during mounting of the guide rails
_Source: BMK_
### horizontal movement

The horizontal movement is provided by the locomobile, on top of the Barrier. The locomobile pushes off from the guide tower via a push/pull coupling rod, thus transferring the force to the Barrier. The vertical bogie rests on top of the locomobile with the aid of a supporting connection. When the locomobile moves vertically, this construction causes the vertical bogie to be moved along. The horizontal movement is realized by a gear wheel toothed rack transmission. Via six driven pinions – large and broad toothed wheels – the locomobile moves along running rails and guide rails on a 210-meter-long toothed rack, which is mounted on top of the Barrier. As the locomobile is fixated horizontally relative to the tower, the floating Barrier will be pushed away from under the locomobile when the motors are started. It is basically the reverse of the movement of the well-known cog railways used in mountainous areas. The train (the locomobile) stays at the same location on top of the Barrier and it is the toothed rack rail (toothed rack) that moves. The six motors of the locomobile have so-called hydro-electric powering. Oil pressure produces the driving force.

However, the movement is more complicated in the case of the Maeslant Barrier. During departure, the locomobile moves up and down, and after sinking, the top of the sector door is no longer horizontal. Deformation will take place under the pressure from sea or river water on the Barrier. The locomobile is partly relieved of that by small ball joints in the pull-push coupling rod and its hydraulic regulation.

The energy for the locomobile is supplied via flexible cable transitions. They absorb the height variations of the top of the Barrier, and thereby also the vertical travel of the locomobile. This variation is approximately 13 meter.

The height of the guide tower is almost 30 meter above Amsterdam Ordnance Datum (NAP). The height was arrived at after an analysis of water levels, movements caused by waves, and the draught and rotations of the Barrier.

### 7.2 The dock door

The motion machineries of the dock door provide the opening and closure of the dock door. The dock door can be opened with two systems. There is a main winch system, consisting of a winch and cable pulleys. The driving mechanism of this system is carried out in duplicate, which provides two possibilities for opening and closure. Should the main winch fail, then a fully independent auxiliary winch system is available. This auxiliary winch can, as a third possibility, only open the dock door. It cannot close it.

The dock door contains large through-flow openings for equalizing the water level in the dock with the water level outside the dock. These openings are operated with hydraulically controlled gates.

### documentation

More information can be found in documentation M00-ALG-05-EN Handbook 3.
8 Control center with the Decision and Control Systems

The control center contains the following:

- the control room;
- the electrical rooms with high-voltage and low-voltage;
- the electronic control system (BesW);
- the computer room of the Decision and Support System (BOS);
- service rooms for maintenance and supervision activities;
- accommodations;
- archive rooms;
- the emergency power aggregate (only on the North side).

The computer system that provides all controls for the equipment of the storm surge Barrier is known as the BesW.

This is an abbreviation of the Dutch for Control System New Waterway. Control of all operational functions, such as equalizing the water in the dock, opening the dock doors, departure of the Barrier, and sinking, is activated when the decision to close is taken.

The BOS makes the decision to activate the Barrier for safety reasons. BOS stands for “Beslis- en Ondersteunend Systeem” (Decision and Support System). This decision of the BOS takes place without human interference. This reduces the probability of decision mistakes. However, the Operational Team does have the possibility to overrule if required. This BOS computer system receives various data as input, such as the predicted water levels on the North Sea, the river discharge and the wind data.

In addition, relevant water levels measured elsewhere are fed to the BOS. The BOS uses the 2D hydrodynamic modeling suite SOBEK. On the basis of the recorded actual water levels, the river discharge and the expected water levels for Hoek van Holland and wind data, the BOS calculates the expected water levels for the locations Rotterdam and Dordrecht.

If the expected water level at Rotterdam or Dordrecht exceeds the predetermined closure level, the BOS system takes action. The entire system is carried out in such a way that optimal reliability is obtained.

The BOS is implemented on error-tolerant hardware. During the software development, special methods and techniques were used to make the software as reliable as possible. A great deal of attention was and is paid to testing.

8.1 Operating the Maeslant Barrier

As closures take place automatically (by the BOS), no real operating takes place, in principle.

An important component of this process is the annual preparation for the storm season and the performance closure.
8.2 Operational Team
Although the BOS can close the Maeslant Barrier and the Hartel Barrier fully automatically, a team is always called up, the Operational Team (OT). This team consists of:

- Leader Barrier Process;
- Head Technical Specialists;
- Head Hydraulics Specialists;
- Duty Officer HCC of the Port Authority;
- Process Overseer;
- Monitor (on each location);
- Hydraulics Specialists;
- Technical Specialists (on each location).

The Operational Team is located at the locations Maeslant Barrier North and South, and on the Hartel Barrier. The Leader Barrier Process and the two heads constitute the Decision Team. All decisions taken during an operational period are taken by the Decision Team.

The Operational Team monitors the progress of the closure and has the possibility of intervening or carrying out corrections, if required. The BOS is the area of attention of the Hydraulics Specialists. All other parts of the Barrier have the attention of the Technical Specialists. All causes of errors that contribute too highly to the failure probability of the Barrier were analyzed in advance. A corrective action is available that can be carried out by the Operational Team.

As being called up for a closure does not happen often, a great deal of attention is paid to training and education of the members of the Operational Team.

**documentation**

More information can be found in Handbook (KS-RWS0501/BOS-2005-554) Decision and Support System –BOS- Description and the scenarios “Storm and Performance Closure”, which are published annually.
9 Water measurement arrays

The water levels in front of and behind the Barrier are essential to the Barrier’s functioning. Both the BOS and the BesW make use of current water levels to control the various processes. That is why the water level data must be sufficiently accurate and reliable. A total of four water measurement arrays (WMAs) is located at a distance of approximately 500 meter from the Barrier, at both sides. Each of the measurement arrays contains two digital water level meters (DWLM or DNM, in Dutch). A DWLM consists of a float of which the distance to a reference point is measured continuously. The data are transmitted to the control center North and processed. In 2011, both WMAs on the seaward side were equipped with radar level meters. Their purpose is to record wave data with which the load on the Barrier can be determined. The radar is suspended from a four-meter-long support.

Figure 24
Water measurement array (WMA)
Source: EVA
Summary

The abutments contain the space for the parking docks and the joint foundations. The front wall of the abutments consists of steel tubular poles combined with sheet piling, the so-called combi wall. The parking docks provide space for the Barrier halves or retaining walls. The walls of the parking dock also consist of combi walls. The floor of the dock was carried out as an extra heavy construction and rests on 562 VIBRO piles.

To allow free floating of the Barrier halves, the depth of the dock is more than eight – running into nine – meter below Amsterdam Ordnance Datum (NAP). When dry, the dock also offers the possibility to inspect the Barrier and carry out maintenance.

The ball joints enable the movements of the Barrier halves, that is, horizontal rotations during departure and return of the sector doors and vertical rotations during sinking and floating. Each ball joint transfers the water pressure to its joint foundation. The actual joint consists of bearing shells and bearing seats that are equipped with a gliding system consisting of synthetic pads.

The concrete joint foundation was designed for friction (foundation on steel). The sill and soil protection fixate the underlying sand of the riverbed. The sill blocks constitute the elements of the sill on which the Barrier rests, when sunken.

The lattice arms are the connecting elements between the ball joint and the Barrier. The lattice arms transfer the water pressure on the Barrier to the ball joint and the joint foundation. The lower pipes of the lattice arms are open, the upper ones closed; the latter contain cables and piping.

The retaining wall is the water-halting element. In cross-section, the retaining wall is L-shaped. By letting water flow in or pumping it out, the sector door is able to sink or float. Fenders are present at the bottom of the retaining wall, and the retaining wall also contains four trim tanks.

The drive mechanism – the locomobile and the vertical bogie in the guide tower – and the ballast system enable the horizontal and vertical movements of the retaining wall. The drive mechanism of the dock door consists of winches and gates.

The control center contains all necessary service rooms, including those for control and operation of the storm surge Barrier. The BesW computer system operates the equipment; the BOS computer system, on the other hand, decides about whether to close the Barrier or not, and controls the main processes.

Four water measurement arrays situated in front of and behind the Barrier ensure that the BOS and BesW always have accurate and reliable water level data.